Int J Life Cycle Assess (2013) 18:1673–1685
DOI 10.1007/s11367-012-0529-1

LIFE CYCLE SUSTAINABILITY ASSESSMENT: FROM LCA TO LCSA

A UNEP/SETAC approach towards a life cycle sustainability assessment—our contribution to Rio+20

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Received: 28 March 2012 / Accepted: 5 November 2012 / Published online: 23 November 2012

Abstract
Purpose To contribute to the upcoming United Nations Conference on Sustainable Development (Rio+20) in 2012 by introducing a life cycle sustainability assessment (LCSA) and showing how it can play a crucial role in moving towards sustainable consumption and production. The publication, titled *Towards a Life Cycle Sustainability Assessment*, and published by the UNEP/SETAC Life Cycle Initiative aims to show how three life cycle techniques—(environmental) LCA, S-LCA and LCC—can be combined as part of an overarching LCSA.

Methods The method was demonstrated by evaluating the characteristics of each phase for each life cycle technique. In defining the goal and scope of an LCSA, for example, different aspects should be taken into account to establish the aim of the study as well as the functional unit, system boundaries, impact category and allocation. Then, the data to be collected for the life cycle sustainability inventory can be either in a unit process or on an organisational level. They can also be quantitative or qualitative. Life cycle sustainability impact assessment should consider the relevance of the impacts as well as the perspective of stakeholders. The interpretation should not add up the results, but rather evaluate them jointly. In order to clarify the approach, a case study is presented to evaluate three types of marble according to the proposed method.

Results and discussion The authors have identified that while LCSA is feasible, following areas need more development: data production and acquisition, methodological development, discussion about LCSA criteria (e.g. cutoff rules), definitions and formats of communication and dissemination of LCSA results and the expansion of research and applications combining (environmental) LCA, LCC and S-LCA. The authors also indicate that it is necessary to develop more examples and cases to improve user capacity to analyse the larger picture and therefore address the three dimensions or pillars of sustainability in a systematic way. Software and database providers are called for in order to facilitate user-friendly and accessible tools to promote LCSAs.

Conclusions The application demonstrated that, although methodological improvements are still needed, important steps towards an overarching sustainability assessment have been accomplished. LCSA is possible and should be pursued; however, more efforts should be made to improve the

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technique and facilitate the studies in order to contribute to a greener economy.

Keywords LCSA · (Environmental) LCA · LCC · S-LCA · Sustainability assessment

1 Introduction

Modern society places enormous stress on the Earth. Indeed, it is often quoted that, if the consumption levels of the world's inhabitants equalled those in the industrialised countries, it would require the resources of more than two Earths. As world population grows from its present seven billion to a predicted nine billion in 2050 (UNFPA 2011), so does the need for natural resources to meet the water, food, clothing, shelter and other basic human necessities. With climate change a reality—as witnessed by declines in biodiversity, growing water scarcity and other unresolved environmental issues that pose great challenges—it is clear that drastic change is needed.

Recognition of this future scenario was given as early as 1972 when the United Nations Conference on the Human Environment (UN 1972) alluded to unsustainable trends within our society due to 'man's capability to transform its surroundings', referring to 'incalculable harm to human beings and the human environment'. This dire warning was reiterated in the Rio Declaration on Environment and Development 20 years later, which states: 'To achieve sustainable development and a higher quality of life for all people, States should reduce and eliminate unsustainable patterns of production and consumption…' (WCED World Commission on Environment and Development 1987). Within that framework, governments and the private sector are called on to give more consideration to the impact of their policies and strategies on the three dimensions of sustainability: (a) environmental, (b) economic and (c) social.

One of the main themes of the Earth Summit (Rio +20 Conference)—a green economy in the context of sustainable development and poverty eradication—is proposed as a key strategy to improve compatibility between the increasing resource needs of the growing population and the Earth's dwindling natural resource stocks. A green economy is one that results in increased human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. This should be achieved by bringing the necessary changes to guarantee a future for life on Earth. It means that decision making on product and process development, investment and policy must address the three dimensions of sustainability by using life cycle thinking (LCT) with an emphasis on the socioeconomic impact. Hence, LCT can be operationalised through life cycle management approaches, techniques and tools.

Applying LCT offers a way of incorporating sustainable development in decision-making processes. This means going beyond the more narrow traditional focus on an enterprise's manufacturing site and taking into account the environmental, social and economic impacts of a product over its entire life cycle and value chain.

UNEP has used the life cycle approach (LCA) since the 1990s and, more specifically, since 2002, through the UNEP/SETAC Life Cycle Initiative, which has contributed, inter alia, to the Marrakech Process on Sustainable Consumption and Production (SCP) and to the development of a 10-Year Framework of Programmes on SCP and to UNEP's Green Economy Initiative.

One aim of the UNEP/SETAC Life Cycle Initiative has been to enhance the global consensus and relevance of existing and emerging life cycle methodologies and data management. In line with that, the UNEP/SETAC Life Cycle Initiative began with a focus on (environmental) LCA and continued its work by considering the 'triple-bottom-line sustainable development' perspective. An initial major contribution was the publication of the *Guidelines for Social Life Cycle Assessment of Products* (UNEP/SETAC 2009). It was followed by *Towards a Life Cycle Sustainability Assessment* (UNEP/SETAC 2011a), which is a publication that describes not only environmental and social aspects but also key findings from the Code of Practice for Environmental LCC (Swarr et al. 2011). In this sense, the aim of the publication is to contribute to the sustainable development discussions of the United Nations Conference on Sustainable Development (Earth Summit 2012).

Towards a Life Cycle Sustainability Assessment proposes a way to combine (environmental) LCA, LCC and S-LCA and to be considered as a methodological contribution to the Rio+20 Conference. While using (environmental) LCA to measure the environmental dimension of sustainability is widespread, similar approaches for the economic (LCC) and the social (S-LCA) dimensions of sustainability still have limited application worldwide. These developments are crucial because they allow for the emergence of a life cycle-based approach for sustainability assessment conforming to the ISO 14040 (2006) stages.

The aim of this paper is to summarise the proposal about how the three techniques can be combined into a life cycle sustainability assessment (LCSA). It is not the aim of this paper to present a conclusive approach; rather, it proposes steps towards an LCSA for further improvement and discussion and, hence, to provide useful findings for better-informed decision making.

2 Life cycle sustainability assessment

LCSA refers to the evaluation of all environmental, social and economic negative impacts and benefits of a product throughout its life cycle and how to use the result to support decision-making processes (UNEP/SETAC 2011a). The idea of combining three LCA techniques into an LCSA was first formulated by Klöpffer (2008), followed by Finkbeiner et al. (2010), and is expressed in the following way:

$$\mathrm{LCSA} = (\mathrm{environmental})\ \mathrm{LCA} + \mathrm{LCC} + \mathrm{S{-}LCA}$$

The formal equation introduces the concept that the assessment of sustainability performance of product should be carried out by the contemporary implementation of the three life cycle techniques.

Some efforts were previously made in this direction by combining two LCA techniques (Saling et al. 2002; Itsubo and Inaba 2003; Mazijn et al. 2004; Poulsen and Jensen 2004; Franze and Ciroth 2011) and three of them (Traverso et al. 2012; Vinyes et al. 2011), and a lot of discussion is still ongoing (Weidema 2006; Cavanagh et al. 2006; Grießhammer et al. 2007; Zamagni et al. 2009; Finkbeiner et al. 2010; EFORWOOD 2010; Swarr et al. 2011; Halog and Manik 2011; Spoerri et al. 2011; Vinyes et al. 2011). While the authors acknowledge previous and emerging efforts in combining LCA techniques, it is worth highlighting that a discussion about the previous experiences and ongoing efforts and their limitations are not part of the scope of this paper. In addition, the authors point to several international organisations that have addressed sustainability in businesses and organisations: UN Global Compact, OECD Guidelines for Multinational Businesses, ISO 26000 (Guidance on Social Responsibility) and the Global Reporting Initiative, all of which highlight the importance of *due diligence* in the value chain.

The LCSA framework follows the one established in (environmental) LCA, which is the only technique already standardised (ISO 14040 2006; ISO 14044 2006). A meaningful point to implementation of the combined LCSA approach instead of the doing so separately is that the same system boundary and the same functional unit should be used for all three assessments. Aimed at the dissemination of the practice of LCSA, *Towards a Life Cycle Sustainability Assessment* (UNEP/SETAC 2011a), presents (a) the context that led to LCSA; (b) the characteristics, methods of application and examples of each LC technique; (c) a proposal on how to conduct an LCSA with one example; and (d) a discussion on how to move forward.

Generally speaking, applying LCSA can benefit businesses, decision makers and consumers in several ways. It helps to organise complex environmental, economic and social data in a structured form; clarify the trade-offs between the three sustainability dimensions, life cycle stages and impacts; provide guiding principles to achieve sustainable production while stimulating innovation (by identifying weaknesses and enabling further improvements over the product life cycle); help to raise credibility by communicating useful quantitative and qualitative information about their products and process performances (which can also be used to inform labelling initiatives) and show how to become more responsible by taking into account the full spectrum of impacts associated with their products and services. LCSA can support decision makers in prioritising resources and investments and in choosing sustainable technologies and products. Finally, LCSA supports consumers in determining which products are cost-efficient; have a low environmental impact and are socially responsible and, in general, promote awareness in value chain actors on sustainability issues.

More specifically, some potential benefits of combining the three techniques towards an LCSA include cost reduction (as some data can be collected at the same time), risk reduction of double counting, consistency in the reporting (as the results of the three techniques are based on the same functional unit) and motivated and better engaged stakeholders, especially in developing countries, following iterative consultative processes. In conclusion, life cycle techniques can provide important information for managing the social responsibility of an organisation and its value chain, from the 'cradle to the grave', taking into account all dimensions of sustainable development.

3 Moving towards an LCSA

LCSA can be applied using the four LCA phases according to ISO 14040 (2006) and ISO 14044 (2006) (goal and scope, inventory of resource use and emissions and impact assessment and interpretation). In this section, for each phase, recommendations to perform an LCSA are presented, taking into consideration a combination of the three techniques: (environmental) LCA, (economic) LCC and (social) S-LCA.

3.1 LCSA goal and scope definition

When defining the goal and scope of an LCSA study, one has to take into account that, although the aims of each technique might be different, a common goal and scope should be formulated when combining the techniques towards an LCSA. Relevant scope and definition aspects for each technique that have to be considered include functional unit, system boundaries, impact category and allocation. The functional unit in an LCSA should consider the

technical utility (such as quality, functionality etc.) as well as the social utility (such as convenience, prestige etc.), as required by the (environmental) LCA (Consoli et al. 1993) and the S-LCA (UNEP/SETAC 2009), correspondingly.

Concerning the system boundaries, one or more cutoff criteria could be used (e.g. mass, energy or environmental relevance, working hours and costs) and they could be different for each technique. An additional cutoff criterion is the relevance of the processes, and hence, the authors recommend the incorporation of all processes that are relevant for at least one of the techniques (Fig. 1).[1] If a process is excluded, justification should be provided.

Impact categories should be related to each technique. This will help with subsequent identification and discussion of potential trade-offs and double counting while collecting information for the three techniques and within one impact category

Regarding the allocation criteria, this discussion is relevant when quantitative data are used and if a process results in more than one output. In this case, the question is to which burden should be allocated. In order to do so, the use of physical or economic proportions is suggested, as it is accepted practice when implementing the three techniques separately.

3.2 Life cycle sustainability inventory

Data to be collected and processed to obtain the life cycle sustainability inventory (LCSI) have different characteristics. Figure 2 illustrates the scope of data collection and draws attention to a critical distinction between an (environmental) LCA, an S-LCA and a LCC. ‘While (environmental) LCA works with data reported at the site, facility and processes level, the S-LCA and LCC can make use of data that is [*sic*] gathered and reported at the enterprise (or organization) level as well’.

The suggested LCSI is a process/organisations based life cycle inventory. Economic input–output data may be useful when developing an LCC, but its discussion and examples of its use are not part of this publication. For example, in Fig. 3, working hours, water consumption, CO_2 and N_2O emissions, costs, revenue and the product were collected at the unit process level, whereas the presence of Certification of Management Systems was collected at the organisational level.

In collecting additional information at the organisational level, data at site, facility and process levels are required. Therefore, identifying the chain actors in the product system is essential. The type of data can be quantitative, semi-quantitative or qualitative. In general, (environmental) LCA and LCC use quantitative data; however, in S-LCA, semi-quantitative and qualitative information are also often used, which adds to the challenge of aggregating different types of data along the life cycle. In those cases, one could, for example, express the results as a percentage of processes where child labour occurs (semi-quantitative data) or simply indicate that there is or there is not child labour in the life cycle of a product.

3.3 Life cycle sustainability impact assessment

In selecting the impact categories for a life cycle sustainability impact assessment (LCSIA), the authors suggest following the (UNEP/SETAC 2009), in which the relevance of the impacts based on the stakeholders’ point of views is taken into account. Cases of how stakeholder views can be considered in S-LCA are described by Ciroth and Franze (2011).

The differences in performing an LCIA among the three techniques are notable. For (environmental) LCA, LCIA methods began to consider a more generic approach (CML, 1992; EDIP 1993; Ecoindicator 95 and others) and evolved to allow spatial differentiation, while LCC and S-LCA were designed to use data at site, facility and process levels.

In (environmental) LCA, environmental flows are quantitatively related to the impact categories (either mid- or end-point) according to environmental mechanisms, resulting in characterisation factors for each environmental flow. In S-LCA, due to the fact that limited research is available about the social mechanisms, it is recommended that categories be evaluated according to 31 sub-categories proposed by UNEP and SETAC (2009). In this regard, LCC is simpler, as economic costs and benefits are the only impacts that are taken into account. Nevertheless, externalities may or may not be monetised in the LCC approach (e.g. the number of absent days due to bad health conditions directly caused by inappropriate working conditions). In Fig. 4, an example of LCSIA is presented in which LCSI relates to the corresponding impact within each technique. Notice, however, that there are still no relationships among the impact categories of one technique to another. Although normalisation, aggregation and weighting are optional steps, according to ISO 14040 (2006) and ISO 14044 (2006), due to the early stages of LCSA, the authors (UNEP/SETAC 2011a) do only recommend internal normalisation using them in the context of an LCSA.

3.4 LCSA interpretation

The interpretation requires (semi-)quantitative and qualitative information from the three techniques. All findings

[1] After applying cutoff criteria, system boundaries might differ from one technique to the other. For example, when looking at the life cycle of coffee (Mazijn et al. 2004), the shipping from Latin America to Europe does not have environmental relevance; however, from the S-LCA perspective, bad working conditions might be a factor.

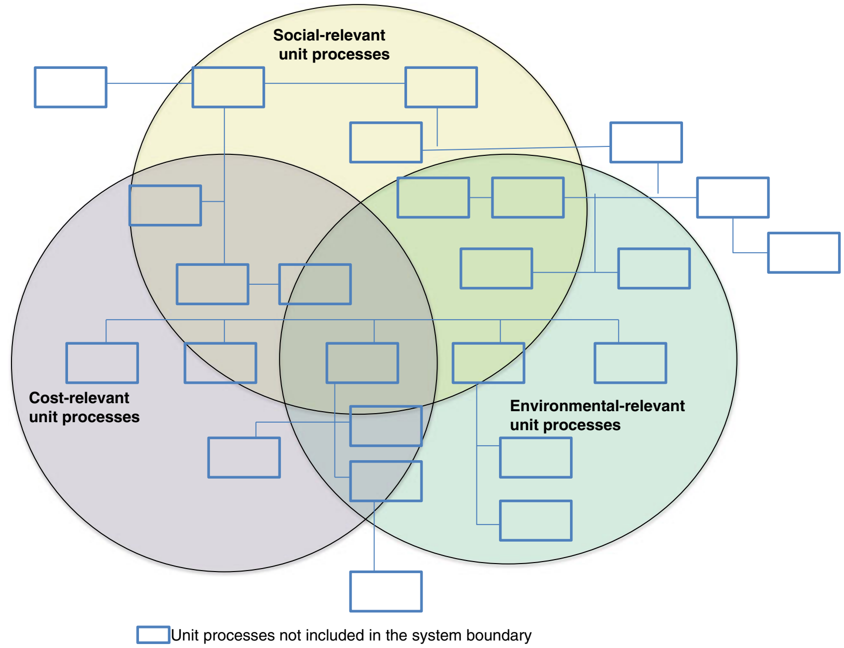


Fig. 1 LCSA product system and system boundaries

need to be checked against data quality and uncertainty. Detailed parallel representation of the three techniques with their results helps the reader and stakeholders identify potential and real impacts and benefits as well as trade-offs among the outcomes of the three techniques. Nevertheless, challenges remain before applying an LCSA.

All aspects required by ISO 14040 (2006) and ISO 14044 (2006) (contribution, dominance, sensitivity, completeness, consistency etc.) are also valid for the interpretation phase of an LCSA. Nevertheless, two additional aspects could be taken into account while interpreting the LCSA results. The first is that, while the uncertainty of quantitative data can be evaluated using statistical methods, sensitivity analysis could be used for qualitative data similar to an S-LCA and following the recommendations from UNEP/SETAC (2009). Secondly, the contribution analysis should be performed for each technique separately since the authors do not recommend the aggregation and weighting of the results.

4 LCSA case of marble slabs

A case study is presented in *Towards a Life Cycle Sustainability Assessment* to illustrate the application of the LCSA approach through specific examples and, thus, to facilitate the understanding of the reader. Moreover, the authors acknowledge that, through a case study, strengths and weakness of the approach proposed could be inferred. Considering its appropriateness and alignment with the specific recommendations presented in chapter 3, the comparison of marble slabs made of Perlato di Sicilia (types A and B) and Bianco Carrara (types C and D) was considered as an example that is based on the study of Capitano et al. (2011). The application was originally carried out to assess and compare environmental, economic and social indicators of the four indicated types of marble slabs and to facilitate discussion of the appropriateness of the results in the identification of potential trade-offs among the three sustainability pillars.

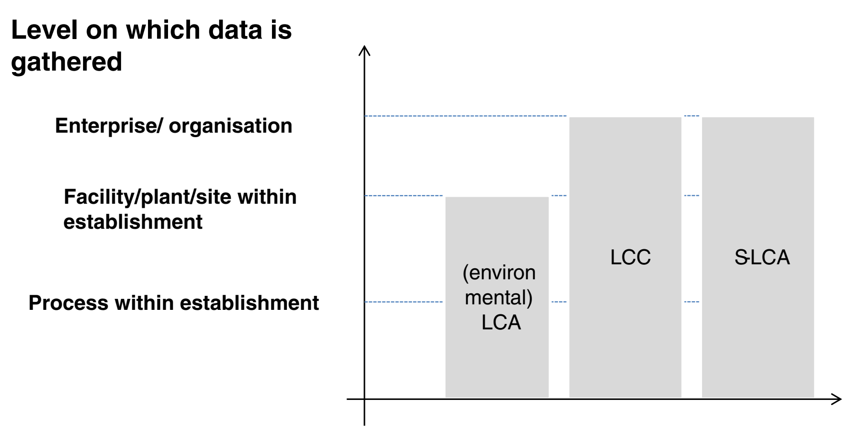
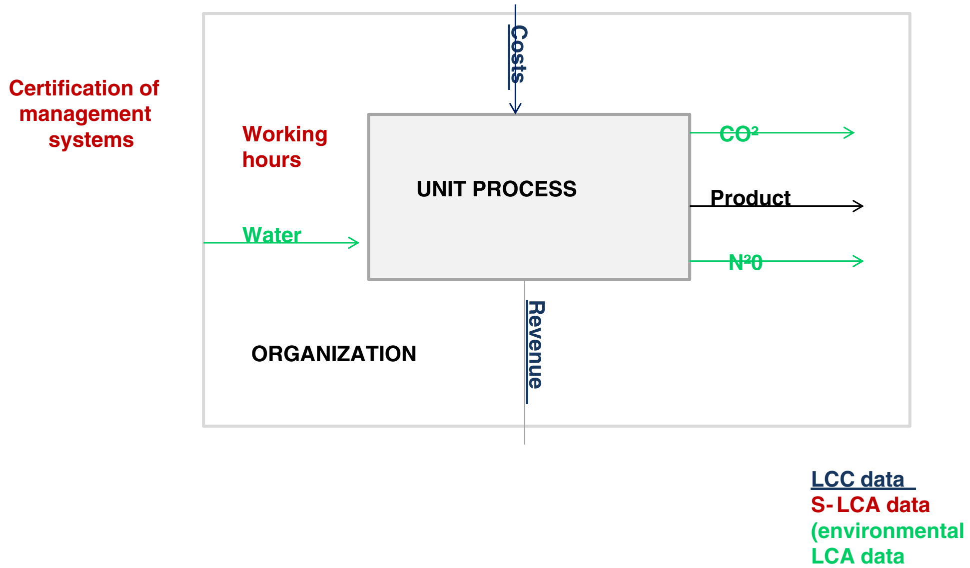


Fig. 2 Level on which data are gathered (adapted from UNEP/SETAC 2009)

Fig. 3 LCSA data collected—an example (UNEP/SETAC 2011a)



4.1 Goal and scope, and system boundary

The goal of the case study was to assess the sustainability performance of four types of Italian marble slabs from the extraction of raw materials to the manufactured and finished product as it is used in the building sector. The following marble products were analysed: 'Perlato di Sicilia' (types A and B) and 'Bianco Carrara' (types C and D), which are the most exported types of Italian marble. The target audience for this study is the marble sector, with the aim of improving their sustainability performance. Furthermore, the results can support local governments in their decision making about marble production in the region. As proposed in the previous section, an identical functional unit is defined, which is the production of 1 m^3 of marble types A, B, C and D. Marble's function is to cover and insulate buildings and surfaces by improving the aesthetic and economic value of the structure and to maintain its integrity easily.

The system boundary includes three main production sites: (a) quarry, (b) manufacturing sawmill and (c) finishing sawmill. The following unit processes are relevant to the three sustainability pillars and, thus, are part of the system boundary: extraction and cutting in the quarry, cutting and resin finishing in the first sawmill, polishing and buffing in the second sawmill, transportation of products along the routes from quarry to two sawmills and transportation of spoils and scraps to specific landfills. The transportation to the final installation of the marble was not considered because marble is exported worldwide and primary data are not available. For the purposes of the study, it is assumed that the impact of the transportation of the four types of marble to the end consumers at the construction sites is identical. The impact during the use stage was considered negligible, as few activities occur during this phase. Moreover, the disposal phase was not considered. In fact, marble products frequently last as long as the buildings in which they are used and are often reused and recycled.

Global warming is one example of an impact category considered in the (environmental) LCA of 1 m^3 of marble. This was calculated using the characterisation factors of the midpoint categories according to Guinée et al. (2002) with updated characterisation factors.

Regarding LCC impact categories, according to Swarr et al. (2011), 'aggregated cost data provide a direct measure of impact and, thus, there is no comparable impact assessment step in LCC'. Therefore, examples of impact categories for marbles are the costs of raw materials and waste disposal. In this case study, the LCC accounts for the following costs per stakeholder group: supplying the materials and services, labour and shareholder benefits.

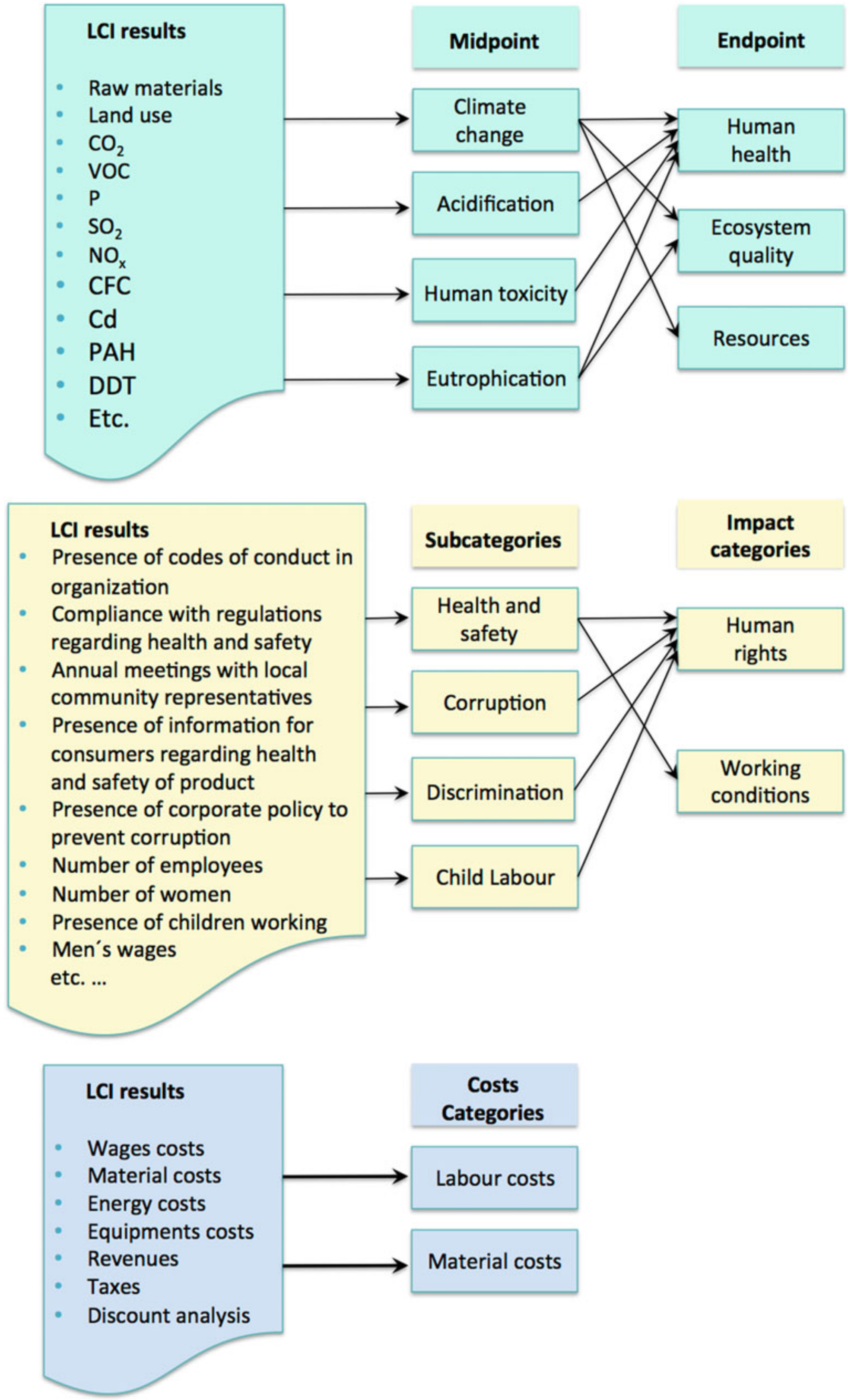
The LCC is implemented to assess costs and benefits of the marble businesses. In fact, as with the S-LCA, the results of the assessment can be very different if the impacts are calculated by considering another stakeholder group (Swarr et al. 2011). It is particularly true for the LCC, where a cost becomes a benefit if the same product is assessed from the perspective of worker or consumer.

For S-LCA, the most affected stakeholder groups could be workers and local communities. 'Fair salary' is an example of a sub-category related to workers that should be considered according to UNEP/SETAC (2009) and the methodological sheets of the S-LCA guidelines (UNEP/SETAC 2010)

4.2 LCSA inventory and impact assessment possibilities

Data are collected for the three main production sites, as described above, to compile exchanges between unit processes and organisation of the product system and the external environment that led to environmental, economic and

Fig. 4 An example of LCSIA



social impacts. Benefits of data collection for each technique towards an LCSA are a more cost- and time-efficient process, reduced risks of double counting (e.g. salaries of workers) and better-informed data collection processes. As a limitation of parallel data collection, it is worth mentioning that, while conducting data inventory, there is a need to

Table 1 Examples of LCSA data categories (Capitano et al. 2011)

Environmental indicators	Economic indicators	Social indicators
(Environmental) LCA indicators	LCC indicators	S-LCA indicators
Fuels consumptions (diesel, methane..)	Labour costs	Total employees
Water use	Equipment costs	Women employees
Electricity consumptions	Fuels costs (diesel and methane)	Number of employees with unlimited contract
Raw materials	Waste disposal costs	Number of employees with limited contract
Greenhouse gas emissions	Electricity costs	Number of accidents related to working
	Revenues	Child labour
		Working hours

understand and analyse the various linkages of the indicators to two or more techniques, which might increase the difficulties during this process.

Examples for data categories based on the marble slabs case study are listed in Table 1. For the example given, inventory results are combined in Table 2 and are the basis for further data processing. To facilitate the combination of the three approaches, for (environmental) LCA and S-LCA, classification and characterisation steps are carried out. LCC data are displayed as costs for different categories.

Traverso et al. (2012) proposed presenting the results in a combined approach by introducing the Life Cycle Sustainability Dashboard (LCSD). This is an adaptation of Jesinghaus's (2000) dashboard of sustainability, which was originally developed to assess and compare the economic, social and environmental factors in local communities.

While acknowledging that a number of LCSA initiatives and approaches currently exist, for the purpose of this publication, the authors highlight the LCSD approach proposed by Traverso et al. (2012) due to the transparency and reader-friendly characteristics that, however, do not mean that other emerging methods are neither appropriate nor transparent nor user-friendly. The LCSD is an ad hoc method that allows for comparison of two or more products and the presentation of the results in a reader-friendly (e.g. using scores and colours) and transparent way, since it keeps the original results of the LCSI. This visual presentation supports a decision-making process in which experts and non-experts of life cycle-based techniques are involved and can be useful in identifying the hot spots for each product and communicate it more easily to non-expert stakeholders.

In implementing the LCSD approach, the results of the LCSI for each product are introduced in the database supporting the LCSD. The software carries out an internal normalisation, assigning for each indicator a value of 1,000 (and a dark green colour) to the product with the best result and a value of 0 (and a dark red colour) to the product with the worst one. The other values are obtained by means of a linear interpolation (see the example of a comparison of S-LCA indicators of four marble types in the top part of Fig. 5. The total number of employees (S01) varies from product to product, and it measures the employment generated in the local community. The best result is obtained for the marble 'Bianco Carrara' type C and the worst one for the marble 'Bianco Carrara' type D).

The authors prevent an aggregation of results of the three techniques, but do acknowledge the possibility of aggregation within each of them, which is the approach followed by Traverso et al. (2012) through an aggregated index for the LCA, LCC and S-LCA results. In support of the operation.alisation of the LCSD, Traverso et al. (2012) assigned the same weight to each indicator. A detailed description of the LCSD can be found in Traverso et al. 2012. Capitano et al. (2011) do not suggest that the best result of an S-LCA is equal to the best result of an LCC;

Table 2 Examples of LCSI results per category and technique for the marble slabs case study (Capitano et al. 2011)

Type of marble	(Environmental) LCA		LCC		S-LCA	
	Embodied energy (MJ/FU)	Global warming potential ($kgCO_2e/m^3$)	Extraction and production costs (€/m^3)	Electricity costs (€/m^3)	Total number of employees (N^o/m^3)	Employees with limited contract (N^o/m^3)
Perlato di Sicilia A	1,224.2	186.5	251.02	39.17	0.0053	0.0000615
Perlato di Sicilia B	1,470.5	257.5	213.75	28.80	0.002780	0
Bianco Carrara C	698.7	109.9	89	2	0.00796	0.0002228
Bianco Carrara D	1,414.8	37.4	20	1	0.00033	2.333E−05

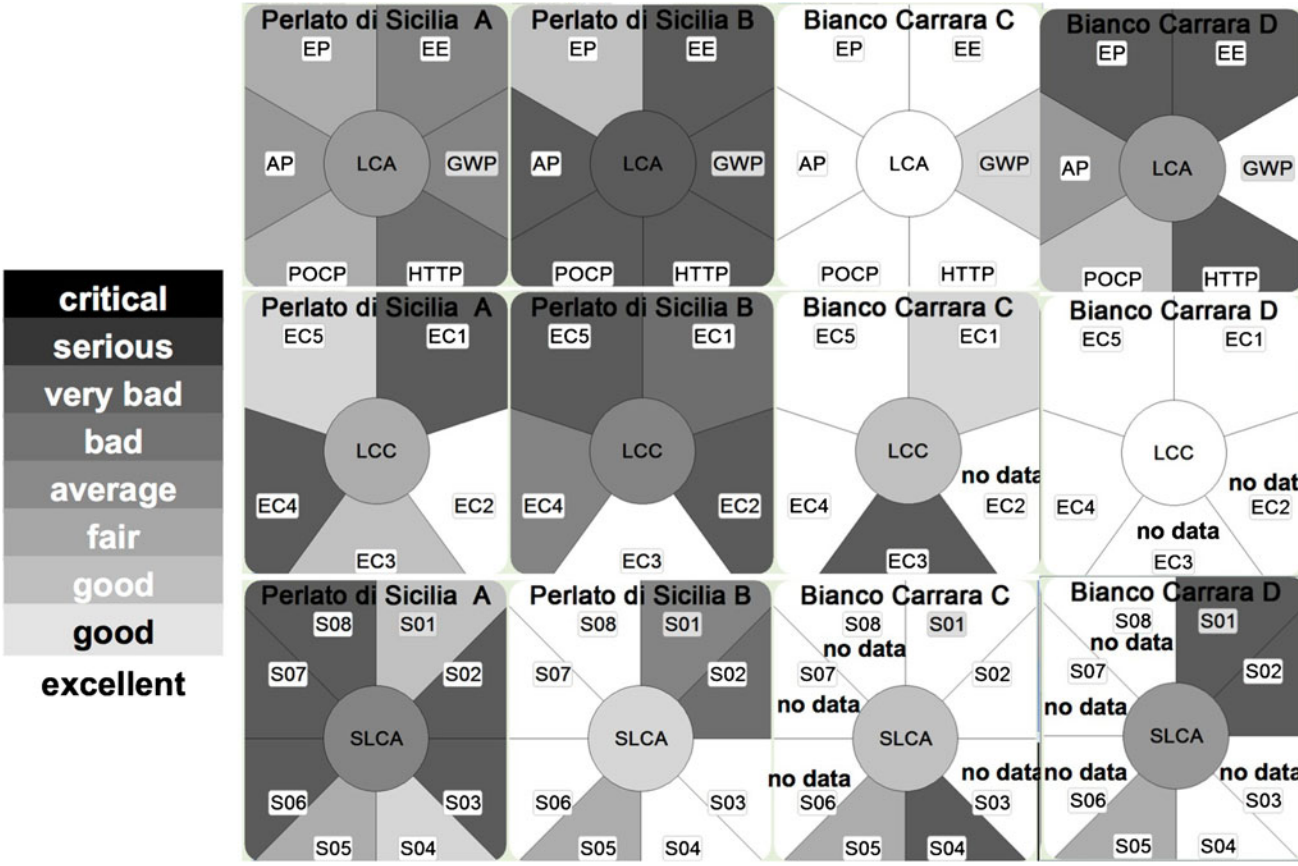


Fig. 5 LCSD marble slabs results by indicators and topic

rather, they suggest reading the results together, e.g. marble type A presented the best results in 'working conditions' and in 'revenues'. A detailed report of the LCSD results and the scores obtained for each indicator is shown in Tables 3, 4 and 5.

The authors of this paper acknowledge that a science-based methodology, in consultation with relevant stakeholders to estimate specific weights for the indicators, would help increase the quality of the results. The development of an overall integrated index for the three techniques—which is the mathematical average of the scores of each technique—is a next step proposed by Traverso et al. (2012); however, as highlighted previously, the authors prevent this type of aggregation. Traverso et al. define this index as a 'sustainability performance' indicator and suggests the use of this value for comparative assertion. The use of this overall index is not recommended because it does not give transparent results about the product. The lower part of Fig. 6 presents the results obtained for four different marble slabs (types A, B, C and D) and for the three techniques applied—S-LCA, LCC and (environmental) LCA—in different colours according to their performance (Capitano et al. 2011). The results suggest that marble C (Bianco Carrara) had the best performance with the three techniques, even though marble D presents better results for LCC. Furthermore, it suggests that there are trade-offs in the case of marbles A, B and D. That is to say, although marble B has better S-LCA results than marble A, it presents worse (environmental) LCA and LCC results than marble A. Moreover, marble D has the best economic performance among the four products, but only average social and environmental performances. Additional limitations of the use of this approach refer to the data unavailability.

Table 3 Resulted scores of the Life Cycle Sustainability Dashboard—related to the (environmental) LCA

Type of marble	Embodied energy	Global warming potential	Human toxicity potential	Photochemical oxidation	acidification	Eutrophication
Perlato di Sicilia B	0	0	0	0	0	581
Bianco Carrara C	1,000	671	1,000	1,000	1,000	1,000
Bianco Carrara D	72	1,000	76	576	340	0

Table 4 Resulted scores of the Life Cycle Sustainability Dashboard—related to the LCC

Type of marble	EC01 Extraction and production costs	EC02 Fuel costs	EC03 Waste disposal costs	EC04 Electricity costs	EC05 Revenues
Perlato di Sicilia A	251	1,000	621	0	768
Perlato di Sicilia B	161	0	1,000	271	0
Bianco Carrara C	701	No data	0	1,000	1,000
Bianco Carrara D	1,000	No data	No data	1,000	1,000

5 Discussion

The authors would like to underscore the value of case studies such as the one presented in chapter 5, which help to build knowledge and practice. More demonstration case studies are needed that show that combining E-LCA, S-LCA and LCC is beneficial for greater understanding of sustainable production and consumption patterns and the possible trade-offs between sustainability concerns (cf. the three dimensions of sustainable development). This is important for decision making by public authorities and business to overcome artefacts by, for example, supporting a product that is environmentally positive but socially questionable (cf. the laptop study of Franze and Ciroth 2011).

While LCSA offers a basis for an integrated approach, potential overlaps must be identified and double counting avoided when applying the three techniques. Therefore, more examples and cases should be developed to improve user capacity to analyse the whole picture and the three dimensions of sustainability and doing so in a systematic manner.

Within the context of an S-LCA, product utility and social acceptability of products are emphasised. In practice, it is not frequently applied in E-LCA and LCC. Therefore, more expertise and experience should be gained when elaborating an LCSA.

Stakeholder involvement in LCSA derives from the experiences with S-LCA. Neither in E-LCA nor in LCC is the involvement common practice. In order to build trust in the combined approach towards an LCSA, more guidance and examples of stakeholder involvement in its development and review through iterative processes should be provided to underline the importance of strong involvement of concerned parties (i.e. the stakeholders). Similar to S-LCA (UNEP/SETAC 2009), the stakeholder categories could comprise workers, consumers, local communities, society and value chain actors. Additional categories or further differentiations or sub-groups could be added, and justification of inclusion or exclusion would need to be provided.

Not all processes are significant for each technique. Further research and case studies will help to assess in a better way for each technique which processes are the most significant and which are less significant and may, therefore, be cut off. This may lead to the inclusion of different processes within the system studied under one technique. In general, it is strongly suggested that LCSA practitioners report about their system boundary practices so that guidelines may be developed in future. The general methodological development for modelling in an LCSA, such as cutoff criteria or allocation, can also benefit from practitioners' reports.

Data production and acquisition are a crucial part of the analysis. Currently, there is a lack of crucial data related to several critical areas in an LCSA. It is expected that broader availability of reliable and suitable data can strengthen the method development. The use of the UNEP/SETAC Global Guidance Principles for LCA Databases (UNEP/SETAC 2011b) could guide these future data development efforts worldwide.

Impact assessment methodologies for LCSA techniques are under development and are an open field for future research. Discussions on areas of protection need to take place (e.g. in both an environmental impact assessment and when evaluating social and economic impacts, or situations

Table 5 Resulted scores of the Life Cycle Sustainability Dashboard—related to the SLCA

Type of marble	S01 Total number of employees	S02 Women employees	S03 Employees with unlimited contract	S04 Employees with limited contract	S05 Child labour	S06 Salary per hour	S07 Employees with insurance	S08 Employees with health check up	S08 Employees registered in the trade union
Perlato di Sicilia A	653	19	0	724	500	1,000	0	0	500
Perlato di Sicilia B	321	181	1,000	1,000	500	0	1,000	1,000	500
Bianco Carrara C	1,000	1,000	No data	0	500	No data	No data	No data	500
Bianco Carrara D	0	0	No data	895	500	No data	No data	No data	500

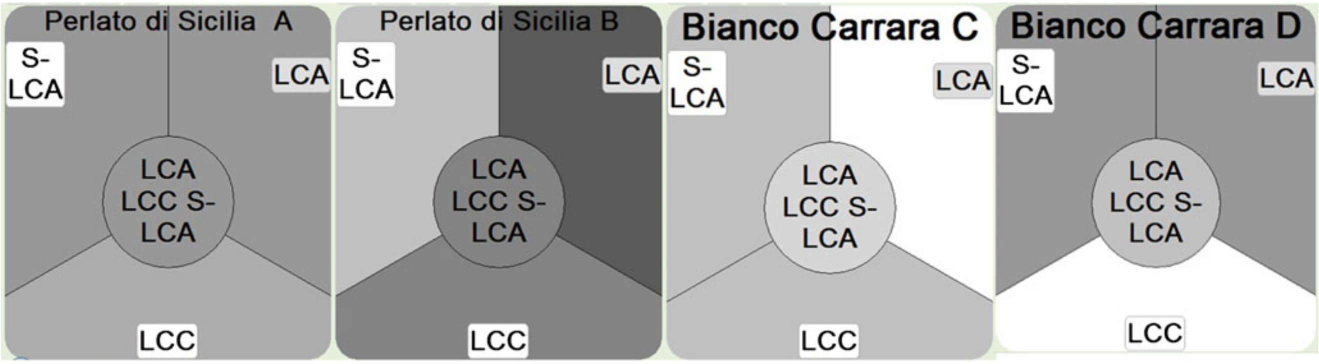


Fig. 6 LCSD marble slabs results by topic and overall index

where cause-and-effect chains are less well-known or even unknown). Moreover, looking at possible trade-offs between the areas of protection in S-LCA, E-LCA and LCC could benefit from further research.

Although the use of different allocation criteria for each technique applied to one activity is not recommended, the authors acknowledge that this is a possible scenario and consider it an area of further research, as well as the possible application of system expansion to avoid allocation. So far, a commonly accepted set of indicators of LCSA has not been identified among the current LCSA initiatives and approaches. It is worth mentioning that, in particular and in spite of several publications and discussions, a set of S-LCA indicators commonly agreed by the scientific community has not yet been achieved.

The use of semi-quantitative and semi-qualitative information adds to the challenge of aggregating different type of data along the life cycle in LCSA. This also influences the formats of communication and dissemination of results that must take into account different dimensions and properties of data and allow for a joint evaluation.

As part of further development and research needs, relationships among the impact categories of one technique to another should be taken into account. This is an important direction for the expansion of research and applications combining (environmental) LCA, LCC and S-LCA

Moreover, even if the weighting of different indicators of the three techniques and the aggregation in more intuitive (sometimes qualitative) indexes are not suggested, in the usual decision-making processes both procedures are often applied to handle the complexity of the obtained results (Finkbeiner et al. 2010). The interpretation procedures need to be revised from different angles, and more cases and experiences would help to clarify the needs and best ways to interpret and communicate the LCSA results. According to Traverso et al. 2012, the LCSD methodology has been proposed to compare sustainability performances of the same group of products as an effective supporting tool to present the results in dissemination activities or decision-making processes in which experts and non-expert stakeholders are usually involved.

6 Conclusions

Achieving sustainable consumption and production patterns within a context of sustainable development requires credible science-based techniques to generate knowledge for a better understanding of the product systems. Based on the findings of the case study presented, it can be inferred that an LCSA approach combining the three techniques helps to address jointly the three dimensions of sustainable development and can provide useful results for decision making. Furthermore, it can be assumed that the combined approach helped to avoid that the improvement measures in one area worsened the performance in other areas; that is, by reducing the cost, labour conditions could also have been reduced.

LCSA can play a crucial role in this process, not only at organisational and company levels but also in the context of science–policy interfaces in developed economies, in the developing world and in the empowerment process of consumers in their daily purchasing decisions. Some potential benefits of combining the three techniques are: cost reduction, as some data can be collected at the same time; risk reduction of double counting; consistency in the reporting, as the results of the three techniques are based on the same functional unit; and motivated and better engaged stakeholders, particularly in developing countries following iterative consultative processes.

Based on stakeholder consultations and international peer review processed where more than 20 acknowledged experts and stakeholders participated between 2010 and 2011, the authors conclude that the areas that need more development in order to advance the implementation of LCSA approaches are the following: product utility and social acceptability definitions, data production and acquisition; double counting related issues; discussion of LCSA criteria (e.g. cutoff rules and allocation), definitions and formats of communication and dissemination of LCSA results; and the expansion of research and applications combining (environmental) LCA, LCC and S-LCA. Moreover, software and database providers are called on to identify reliable data and to facilitate its access to promote LCSAs. Furthermore, the authors also believe that there is a need for

more demonstrative examples and guidance of stakeholder involvement in LCSAs and of how to address the perspective of future generations in research when implementing an LCSA approach to prevent trade-offs.

A set of indicators for LCSA cannot be provided at this point, since it requires more experience from application of the approach. The expected insights from applications will help to understand better the relationship between different impact categories, including across different life cycle-based techniques and the possibility of suggesting areas of protection (or possibly end-point categories). This is seen as a requirement for setting up indicators. Subsequent aggregation and weighting steps to derive an overall sustainability score is not recommended as a stand-alone result, but it might help to clarify trends and options, thereby supporting communication and dissemination.

This work was prepared as a contribution to the methodological discussions on how to assess sustainability at the Rio +20 Conference. The authors acknowledge that, while more research and applications are needed on LCSA, its application is already feasible and should advance the learning curve of societies, especially in resource-limited developing countries that are eager to move towards more sustainable societies.

Acknowledgments The authors of this article would like to thank the other co-authors of *Towards a Life Cycle Assessment of Products*: Walter Klöpffer, Matthias Finkbeiner, Andreas Ciroth, Siddhart Prakash and Gina Vickery-Niederman, as well as the members of the International Life Cycle Board of the UNEP/SETAC Life Cycle Initiative for their support.

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